CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

MINES BRANCH INVESTIGATION REPORT IR 72-35

ARE 4 x 8-INCH CONCRETE CYLINDERS AS GOOD AS 6 x 12-INCH CYLINDERS FOR QUALITY CONTROL OF CONCRETE?

by

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MINERAL PROCESSING DIVISION

COPY NO.

MAY 1973

Unclassified

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SUMMARY OF RESULTS

The 4 x 8-inch (10 x 20-cm) concrete cylinders are not as good as 6 x 12-inch (15 x 30-cm) cylinders for quality control of concrete.

The compressive strengths of the former are generally higher than those of the latter. Below 3000 psi (211 kg/cm^2), the average value of the ratio of the strength of the two sizes of cylinders at 28 days is 1.09; above 3000 psi (211 kg/cm^2) the corresponding value of the ratio reaches 1.16.

The standard deviation of the compressive strength of test cylinders increases with a decrease in the cylinder diameter. The average value of the standard deviation of 28-day test results for 3000- psi (211-kg/cm^2) strength level is 179 psi (12.6 kg/cm^2) for 4 x 8-inch (10 x 20-cm) and 37 psi (2.6 kg/cm^2) for 6 x 12-inch (15 x 30-cm) cylinders.

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INTRODUCTION

The standardization of form and size of test specimens is necessary in testing materials, particularly concrete. In a standard test, the compressive strength of concrete is determined by loading a 6 x 12-inch (15 x 30-cm) cylinder to failure. From the cross section of the cylinder and the total load indicated on the machine, the compressive strength is calculated. A cylinder of the above size weighs about 29 lb (13 kg) in a saturated, surface-dry condition and contains approximately 0.2 ft^3 (0.0057 m^3) of concrete. A number of attempts have been made over the years to reduce the size of the cylinder to 4 x 8 in. (10 x 20 cm) with corresponding reduction in its weight. In 1971, Canadian Standards Association (CSA) Committee A23.1 on Concrete Materials and Methods of Concrete Construction was approached by a cement company to consider the adoption of the 4 x 8-inch cylinder as the standard specimen for the compressive test of concrete(1). Since then, this cylinder has been used as a control specimen in one project in British Columbia. Following the representations made to the CSA, Committee A23.1 discussed the matter at its October 1972 meeting at Gravenhurst, Ontario(2). The consensus was that, because of lack of sufficient data, it was premature to suggest any change in the size of the standard specimen. This view has prevailed in ASTM Committee C-9 for several years.

This investigation reports data which have become available at the Mines Branch over the past several years as to the relative merits of 4 x 8-inch and 6 x 12-inch cylinders for quality control of concrete.

SCOPE OF INVESTIGATION

In this study, test data from a number of investigations have been analyzed. The types of concrete investigated incorporated limestone and gravel stone, as the coarse aggregates, and natural sands as the fine aggregates. The nominal water/cement ratios (by weight) varied from 0.33 to 0.87. Each set of test specimens consisted of two 4 x 8-inch (10 x 20-cm) and two 6 x 12-inch (15 x 30-cm) cylinders, cured under standard moist-room conditions and tested at ages ranging from 3 days to about 8 months. In some cases, test specimens cured under field conditions were also investigated. In all, about 200 each of 4 x 8-inch and 6 x 12-inch cylinders were tested and the test results were subjected to statistical analysis.

EARLIER RESEARCH

Gonnerman(3) was among the earliest researchers to look into the effect of size and shape of test specimens on compressive strength of concrete. They investigated the effect of size of cylinders on compressive strength while varying such parameters as type, size, and grading of aggregates. The tests were made at 7-day to 1-year age on 1755 concrete specimens. They concluded that the decrease in strength with increasing size of cylinder was not important for diameters under 6 inches (15 cm). No statistical studies were done on the within-batch variation of test results.

The United States Bureau of Reclamation(4) has published data for relative strengths to be expected when the same concrete is tested in cylinders between 2 and 36 in. (5 and 91 cm) in diameter with length/diameter ratio remaining constant at 2. It is to be noted that concrete containing up to 3/8-inch (9.5-mm) and 3/4-inch (19-mm) aggregate was not tested in cylinders larger than 18 and 24 inches (45 and 61 cm) in diameter respectively; concrete containing 1 1/2-inch (37.5-mm) aggregate was not tested in cylinders smaller than 6 inches (15 cm) in diameter. The size effect is most marked for diameters between 2 and 18 inches (5 and 45 cm), beyond which the size effect is not apparent, i.e., a further increase in the diameter of the cylinder does not lead to an appreciable decrease in strength. The strength of 4 x 8-inch (10 x 20-cm) cylinders is about 104 per cent of that of 6 x 12-inch (15 x 30-cm) cylinders. No data are given as to the strength of concrete tested.

Neville[5] has suggested a general relation between the strength of concrete and the shape and size of the specimen in terms of (V/hd) + (h/d) where V = volume of specimen, h = its height, and d its lateral dimension. The fit of the experimental data to the relation postulated is shown in Figure 1. The effect of strength level of concrete on the validity of this relationship is not discussed except to state that the strength level of concrete and the fineness modulus of aggregate influence the relation between the strengths of concrete specimens of different shapes and sizes.

Recently Pomeroy[6] has published data on the effect of curing conditions and cube size on the crushing strength of concrete. The principal variables investigated were cube size, curing regimes, and maximum aggregate size. The other variables considered were the effect of mix proportions and age of test. No admixtures were incorporated in the concretes which were made from ordinary portland cements and Thames Valley aggregates. Pomeroy made the following observations on the results of his experimental work:

(1) for water-cured concretes, the crushing strength of small cubes is greater than that of large ones, provided the concrete is strong [(in excess of about 10,150 psi (710 kg/cm^2) for 4-inch (10-cm) cube].

(2) air-drying concrete after moist curing for seven days can completely reverse the size effects, the crushing strength of small specimens becoming significantly lower than that of large ones.

(3) the effect of air-drying immediately after demoulding can reduce the crushing strength of 4-in. (10-cm) cubes to less than that of moist cured concrete.

(4) the indirect tensile strength of cubes is affected neither by specimen size nor by the drying history.

(5) the crushing strength of small specimens of concrete may decrease if drying at 65 per cent relative humidity is prolonged.

(6) strength variability is greater for small specimens than for large ones.

(7) the crushing strength of concretes, particularly if the paste matrix is weak, falls when the maximum aggregate size is about one-third of the specimen dimension.

PRESENT INVESTIGATION

Materials Used and Mix Proportions

The test data analyzed in this report have been taken from a number of investigations performed at the Mines Branch during the past several years. For projects A and B[7,8], the concrete was mixed in a counter-current laboratory mixer in 2-ft^3 batches. For the remaining projects C,D,E, and F[9,10,11,12] concrete was obtained from a local ready-mix concrete supplier.

Normal portland cement (CSA Type 10 = ASTM Type 1) was used for all the concrete mixes. The physical properties and chemical analysis of a typical batch of cement are given in Appendix Table 1.

The coarse aggregate was either crushed limestone or gravelstone up to one inch (25 mm) in size, and natural sand was the fine aggregate. For mixes made in the laboratory, the sand was separated into different size fractions and then recombined to a specific grading.

The grading and physical properties of both the coarse and fine aggregates are given in Appendix Tables 2, 3, 8, 9, 13, and 14.

The mix proportions and the properties of fresh concrete, i.e., temperature, slump, unit weight and air content, are given in Appendix Tables 4, 10, 16, 18, 23, and 28.

Darex air-entraining agent was used in all the mixes; the concrete that was obtained from the ready-mix supplier also incorporated a water-reducing agent.

Casting of Test Specimens

All 4 x 8-inch (10 x 20-cm) and 6 x 12-inch (15 x 30-cm) test specimens were cast in heavy-duty steel moulds (Figure 2) having walls 1/4 inch (6.3 cm) thick.

All cylindrical specimens were compacted by hand rodding (ASTM Standard C31-69); the 6 x 12-inch cylinders were compacted in three equal layers and the 4 x 8-inch cylinders were compacted in two equal layers, each layer being rodded 25 times by a bullet-nosed steel rod. For a project, it was ensured that the same operator performed the hand rodding of the specimens.

Immediately after casting, the moulds were covered by glass plates which, were covered by wet burlap, kept wet during the next 24 hours. Following this, the moulds were removed (Figure 3) and the test cylinders were transferred to a moist-curing room maintained at 73.4 $\pm$ 3°F (23 $\pm$ 1.7°C) and 100 per cent relative humidity. In projects C, D, E, and F, which were partially done in the field, companion specimens of both sizes were cast, to be left in the field for curing under field conditions after initial moist curing for 72 hours.

All test cylinders were tested in a 600,000-lb (271,800-kg) Amsler testing machine. Before testing, the cylinders were capped with a sulphur-flint mixture.

PRESENTATION OF TEST RESULTS

Detailed test results are presented in Appendix Tables 6, 7, 11, 12, 17, 20 to 22, 24 to 27, and 29 to 31. Also included in these Tables are the within-batch coefficients of variation for the compressive strengths of both 4 x 8-inch (10 x 20-cm) and 6 x 12-inch (15 x 30-cm) test cylinders. The densities of hardened concrete, where available, are given in Appendix Tables 5 and 19.

The plots of the test results are shown in Figures 4 to 9, on which lines of equality are also shown. The test results were not subjected to regression analyses.

DISCUSSION OF TEST RESULTS

Size Effect

Figures 4 to 9 show that compressive strengths of 6 x 12-inch cylinders are generally lower than those of 4 x 8-inch cylinders. The differences in strength between the two sizes of cylinders increase with increasing strength level of concrete. However, there are indications that the foregoing may be reversed when low-strength concrete is being tested.

At 28 days, the ratio of the strength of 4 x 8-inch (10 x 20-cm) cylinders to that of 6 x 12-inch (15 x 30-cm) cylinders, expressed as a percentage is between 84 and 132 per cent. The U.S.B.R.(4) has reported an average value of 104 per cent.

Density Effect

It has been suggested that what is being considered as a "size" effect may actually be a "density" effect because the densities of 4 x 8-inch cylinders are higher than the densities of 6 x 12-inch cylinders. The limited data on densities obtained in this investigation do not fully support this hypothesis. In project "A", where densities of cylinders at 28-day age were available for all the mixes investigated, no consistent relationship is apparent between the densities of the two sizes of cylinders. For gravelstone concrete, the densities of 6 x 12-inch cylinders are generally lower than those of 4 x 8-inch cylinders. However, the reverse is true for limestone concrete. For the concrete mixes of project "D", the 28-day densities of 6 x 12-inch cylinders are only slightly lower than those of 4 x 8-inch cylinders; however, in two out of five cases, this trend reverses itself for the densities at 91 days.

For the study of size effects in which density effect is totally eliminated, more closely controlled experiments will have to be designed than those which have been reported here. In such experiments, input effort for compaction will have to be by vibration rather than by manual rodding. Furthermore, the vibration input will have to be very precisely measured.

Summation - Strength Theory

Tucker(13) has tried to explain the specimen size effect on strength test results by means of "summation - strength" theory. According to this theory:

(a) the strength of the material is independent of the area of the specimen upon which tests are made, provided that the length of the specimens remains unchanged in tension tests and that the length/diameter ratio is constant in compression tests;

(b) the standard deviation of the compressive strength decreases with increase in cylinder diameter; however equal information is obtained when the numbers of cylinders tested are such that the summation of the cross sectional area of the cylinders of the two sizes are equal.

The test results presented here do not appear to fully support the first part of the theory. It has been pointed out earlier that for the same length diameter ratio (this equals 2 for the cylinder sizes investigated in this report) there is an increase in strength with decrease in the diameter of the specimen and the difference in strength increases with strength level of concrete.

As to the second premise of the theory, the test results under analyses tend to support it to a degree. There is an increase in the standard deviation of compressive strength with decrease in cylinder diameter. According to the above theory, approximately twice as many 4 x 8-in. (10 x 20-cm) cylinders as 6 x 12-in. (15 x 30-cm) cylinders need to be tested to obtainethe same degree of precision. This is so because the cross section [25.1 inch^2, (162 cm^2)] of two 4 x 8-in. cylinders approximates the cross section [28.2 inch^2, (18.1 cm^2)] of one 6 x 12-inch cylinder. Normally, in the control of quality of concrete, two 6 x 12-inch cylinders constitute a single test. This means that, according to the above theory, five 4 x 8-inch cylinders will have to be tested for control purposes to obtain the same degree of precision. Unfortunately, standard deviations obtained for the compressive strength results of 4 x 8-inch (10 x 20-cm) and 6 x 12-inch (15 x 30-cm) cylinders do not exactly follow the equation(12)

$$\sigma_a = \frac{\sigma_1}{\sqrt{a}}$$

where σ_a is the standard deviation of the strengths of specimens of cross section a, and σ_1 is the standard deviation of strengths of specimens of unit area. The standard deviations of the test results compiled in the Appendix indicate, that, to obtain the same degree of precision, considerably more than five 4 x 8-inch cylinders will have to be tested instead of two 6 x 12-inch (15 x 30-cm) cylinders. For example, the average value of the standard deviation of 28-day test results, for a strength level of about 3000 psi (211 kg/cm^2), is 179 psi (12.6 kg/cm^2) for 4 x 8-inch cylinders and 37 psi (2.6 kg/cm^2) for 6 x 12-inch cylinders.

GENERAL COMMENTS

Apart from the higher strength values and lower degree of precision, the use of 4 x 8-inch cylinders may raise a number of other problems.

The 4 x 8-inch cylinder moulds will not allow the use of concrete made with 1 1/2-inch (37.5-mm) maximum size aggregate because, usually the moulds must have a diameter of three to four times the nominal maximum size of the coarse aggregate being used. It is true that a large amount of concrete used by the ready-mixed concrete industry employs 3/4-inch (19-mm) maximum size aggregate; nevertheless, large volumes of concrete made with 1 1/2-inch (37.6-mm) maximum size aggregate are still being placed in massive structural and pavement sections. The use of 4 x 8-inch cylinders will create difficulties in this regard.

The use of 4 x 8-in. (10 x 20-cm) cylinders will not result in any economies in testing cost. It is highly unlikely that the testing companies will reduce charges per test because of the smaller size of the specimen. On the contrary, the cost of testing would increase if more specimens are to be tested to gain equal precision. Furthermore, there will be little or no savings in manpower because, if inspectors are on the job, it matters little whether they cast a 4 x 8- or a 6 x 12-inch cylinder. Perhaps, more man-hours would be required to cast five small cylinders than two large ones.

A 4 x 8-inch cylinder weighs about 9 lb. (5 kg) whereas a 6 x 12-in. cylinder weighs about 29 lb (13 kg). As it is, 6 x 12-inch cylinders are mishandled at construction sites; the 4 x 8-inch cylinders due to their smaller size and weight would be even more open to abuse.

There is little doubt that, on large projects which are well staffed with competent quality control personnel, the 4 x 8-inch cylinder can be satisfactorily used for over-all production control. But, unfortunately, on projects of this magnitude, there is usually a vast amount of concrete made with plus 1 1/2-inch (37.5-mm) aggregate and this would introduce the problems outlined earlier.

Sometimes, in cases of disputes as to the quality of concrete in structures, it may be necessary to drill cores. To obtain, the same degree of precision as obtained with 6 x 12-inch cores, it would be necessary to drill more than twice the number of 4 x 8-inch cores. This could entail considerable additional expense.

SUMMARY

1. The compressive strengths of 4 x 8-inch (10 x 20-cm) cylinders are higher than those of 6 x 12-inch (15 x 30-cm) cylinders. There are, however, indications that at low strength levels, the reverse may be true.

2. The difference in the strength of two sizes of cylinders increases with an increase in the strength level of concrete.

3. The standard deviation of the compressive strength of test cylinders increases with decrease in the cylinder diameter as indicated by Tucker's "Summation - Strength" theory. However, the magnitude of this increase is such that considerably more than twice the number of 4 x 8-inch cylinders will have to be tested for each 6 x 12-inch cylinder to obtain the same degree of precision.

RECOMMENDATIONS

It is further recommended that more data be obtained on the effect of specimen size on the compressive strength of concrete to confirm the findings of this report. In the new research program, attempts should be made to compact the cylinders in such a way that density of the two sizes of cylinders is the same, thus eliminating the density effect in the final analysis of the test results.

It is recommended that no changes be made in the existing standards to reduce the size of the test cylinders from 6 x 12-in. (15 x 30-cm) to 4 x 8-in. (10 x 20-cm).

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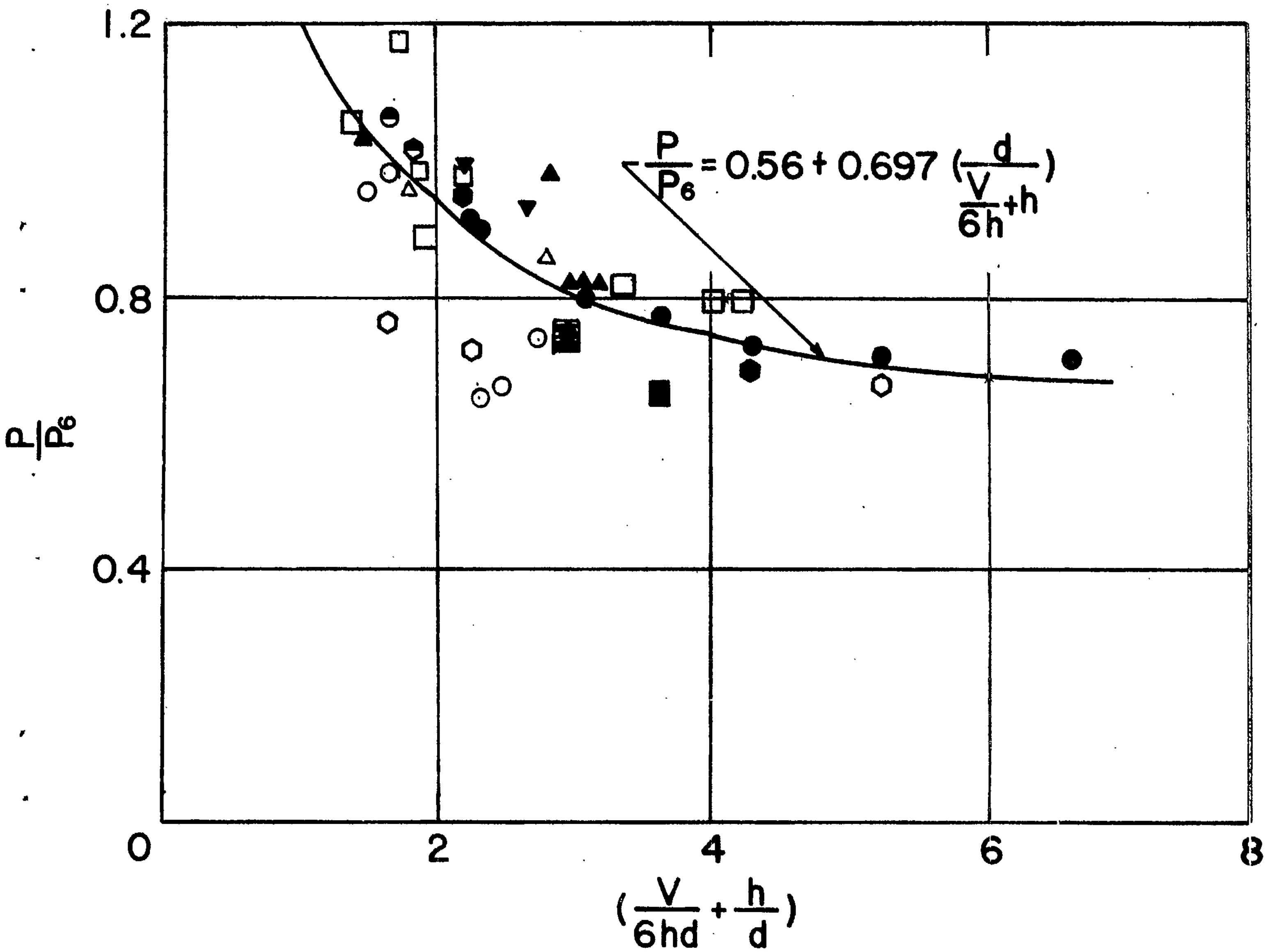

Fig. 1. General relation between ratio of strength of concrete specimens P to strength of 6-in. (15-cm) cube P_6 and $\frac{V}{6hd} + \frac{h}{d}$

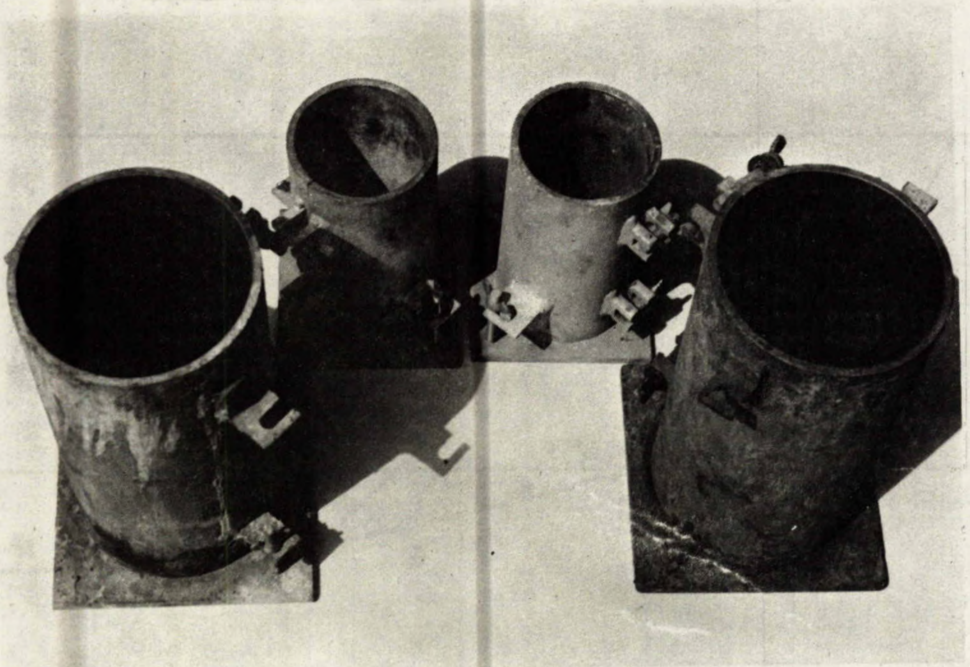

Fig. 2. A view of 4 x 8-in. (10 x 20-cm) and 6 x 12-in. (15 x 30-cm) heavy duty steel moulds.

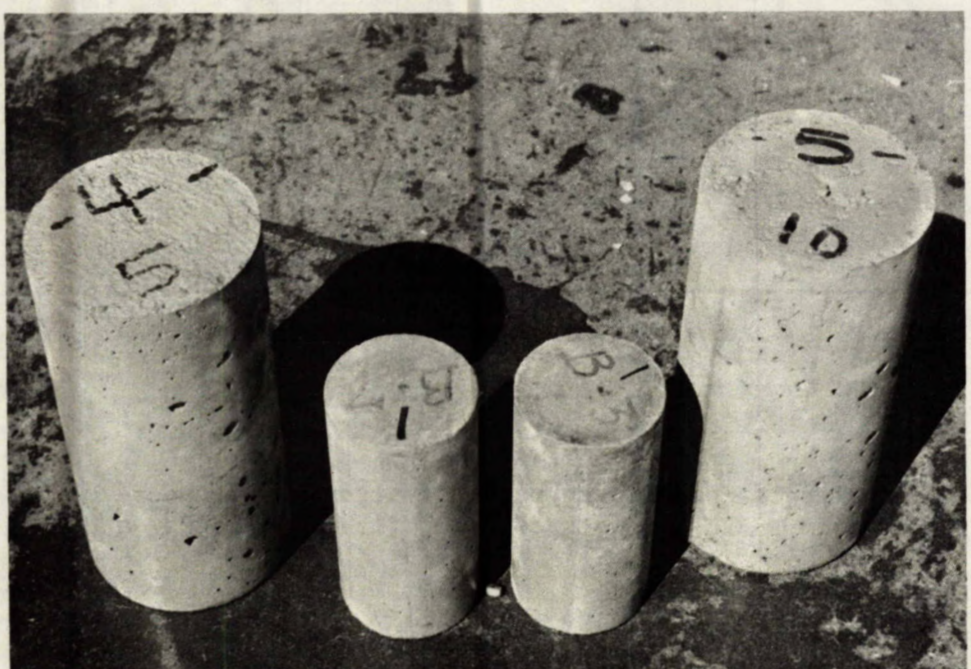

Fig. 3. A view of test cylinders after demoulding.

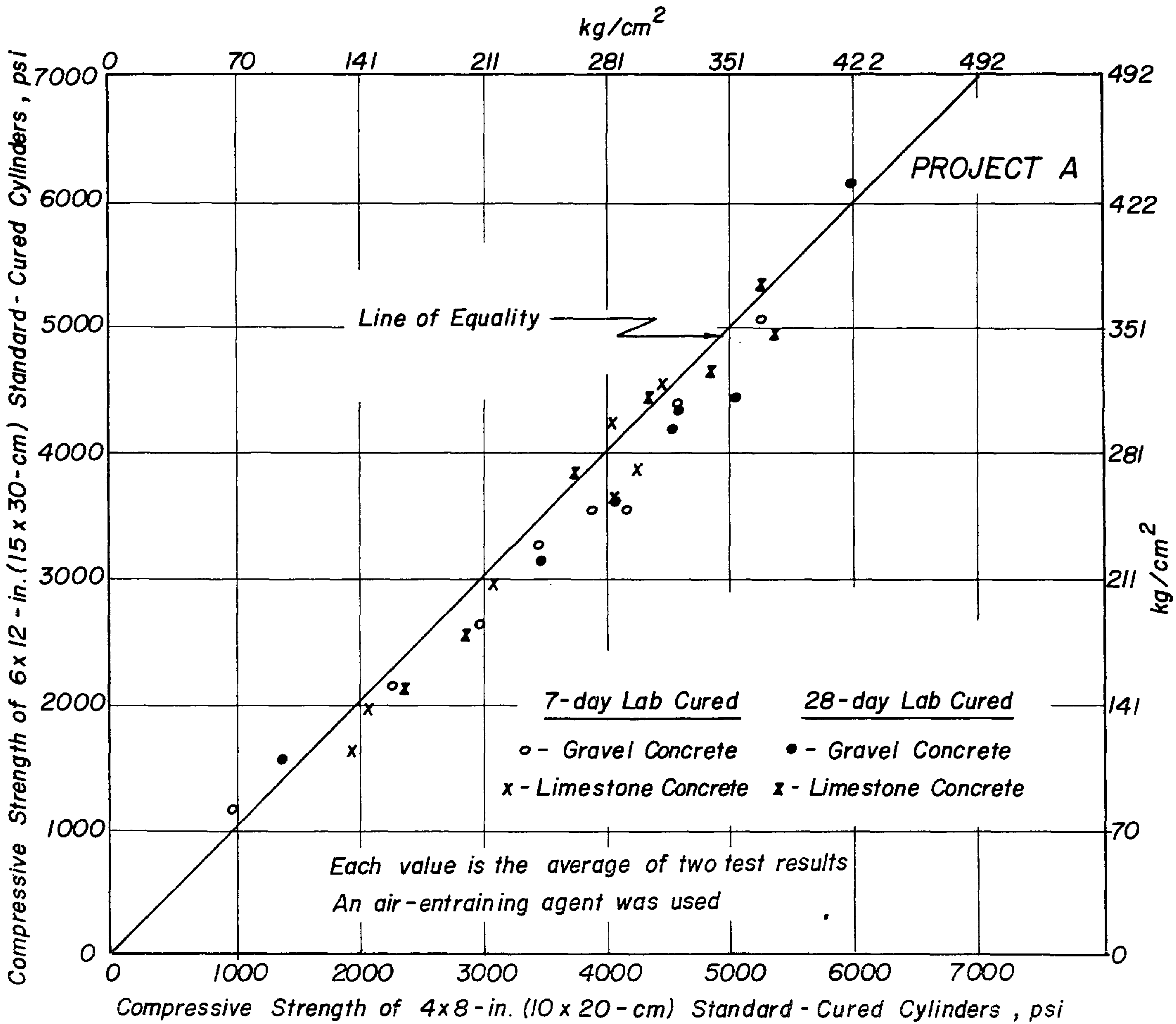

Fig. 4 - Relationship between strength of 4 x 8-in. (10 x 20-cm) and 6 x 12-in. (15 x 30-cm) cylinders - Project A.

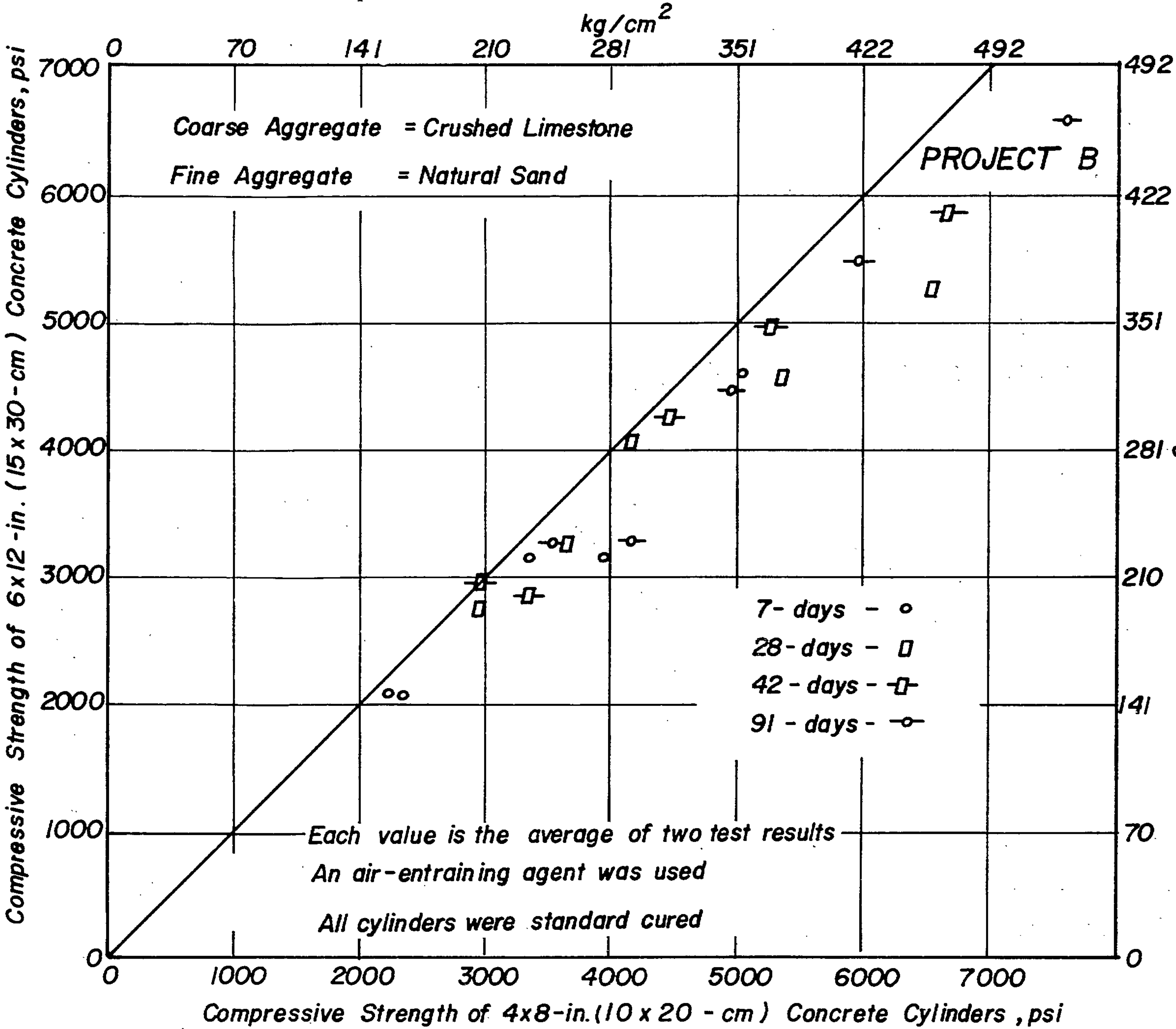

Fig. 5 - Relationship between strength of 4 x 8-in. (10 x 20-cm) and 6 x 12-in. (15 x 30-cm) cylinders - Project B.

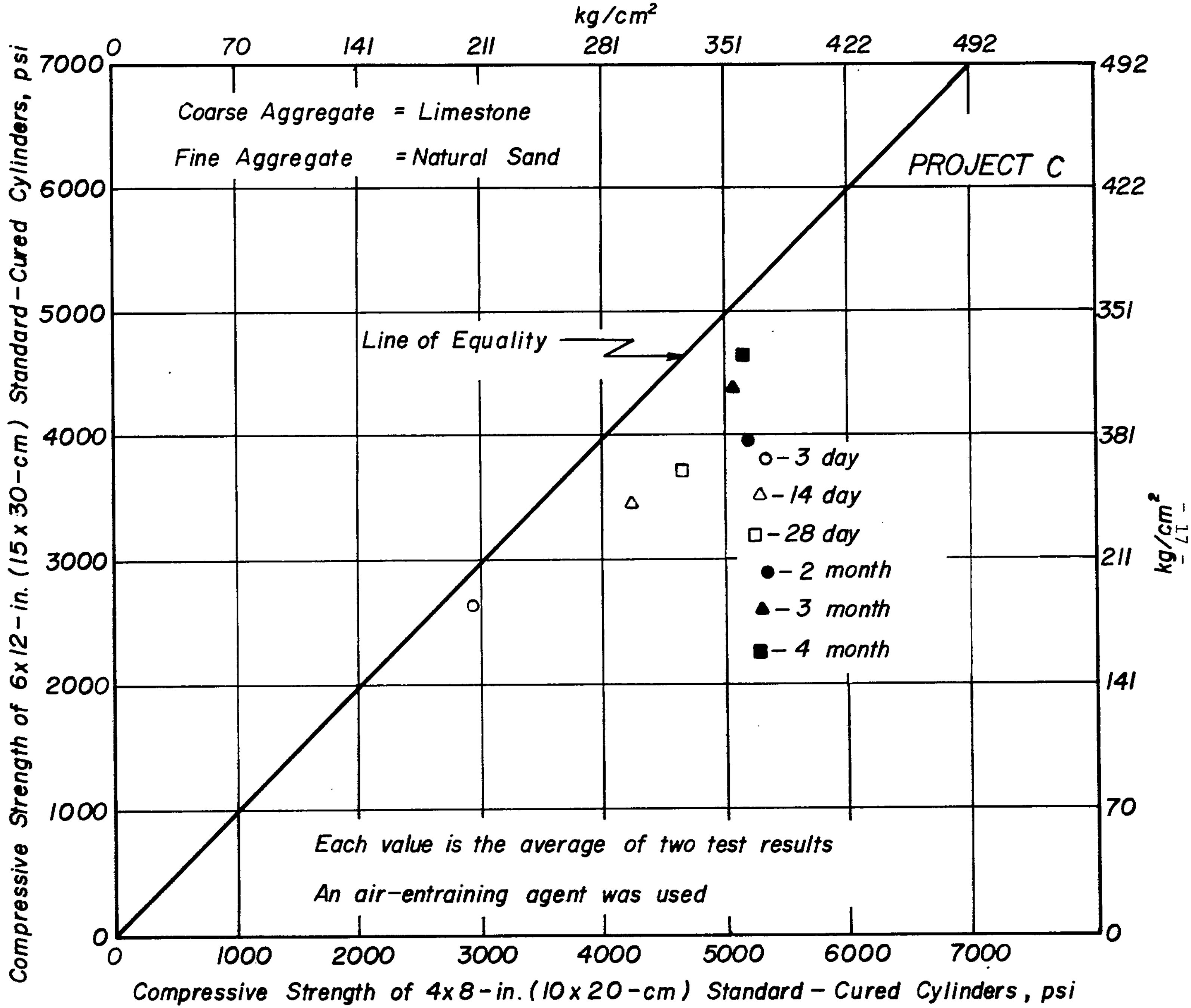

Fig. 6 - Relationship between strength of 4 x 8-in. (10 x 20-cm) and 6 x 12-in. (15 x 20-cm) cylinders - Project C.

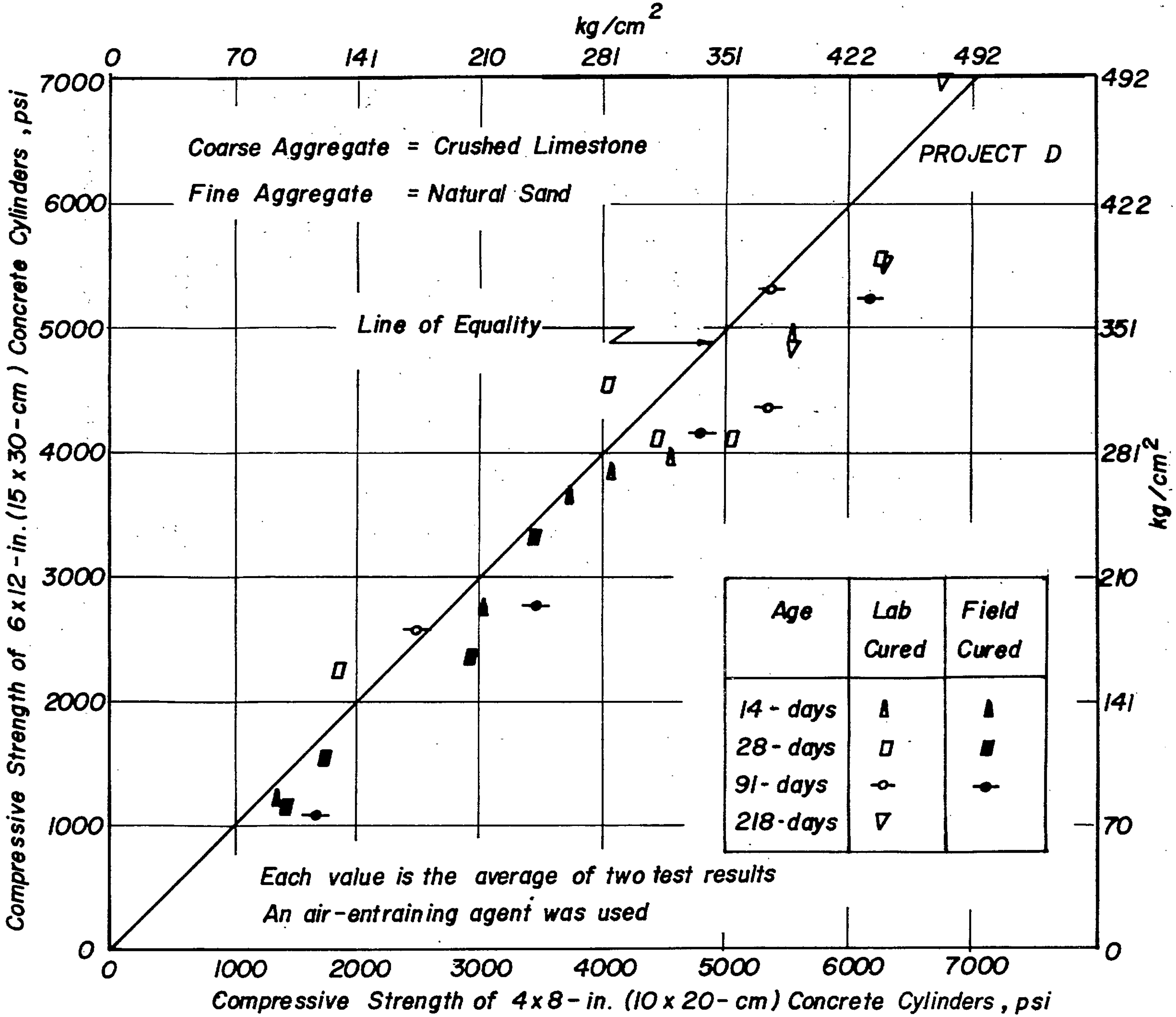

Fig. 7 - Relationship between strength of 4 x 8-in. (10 x 20-cm) and 6 x 12-in. (15 x 30-cm) cylinders - Project D.

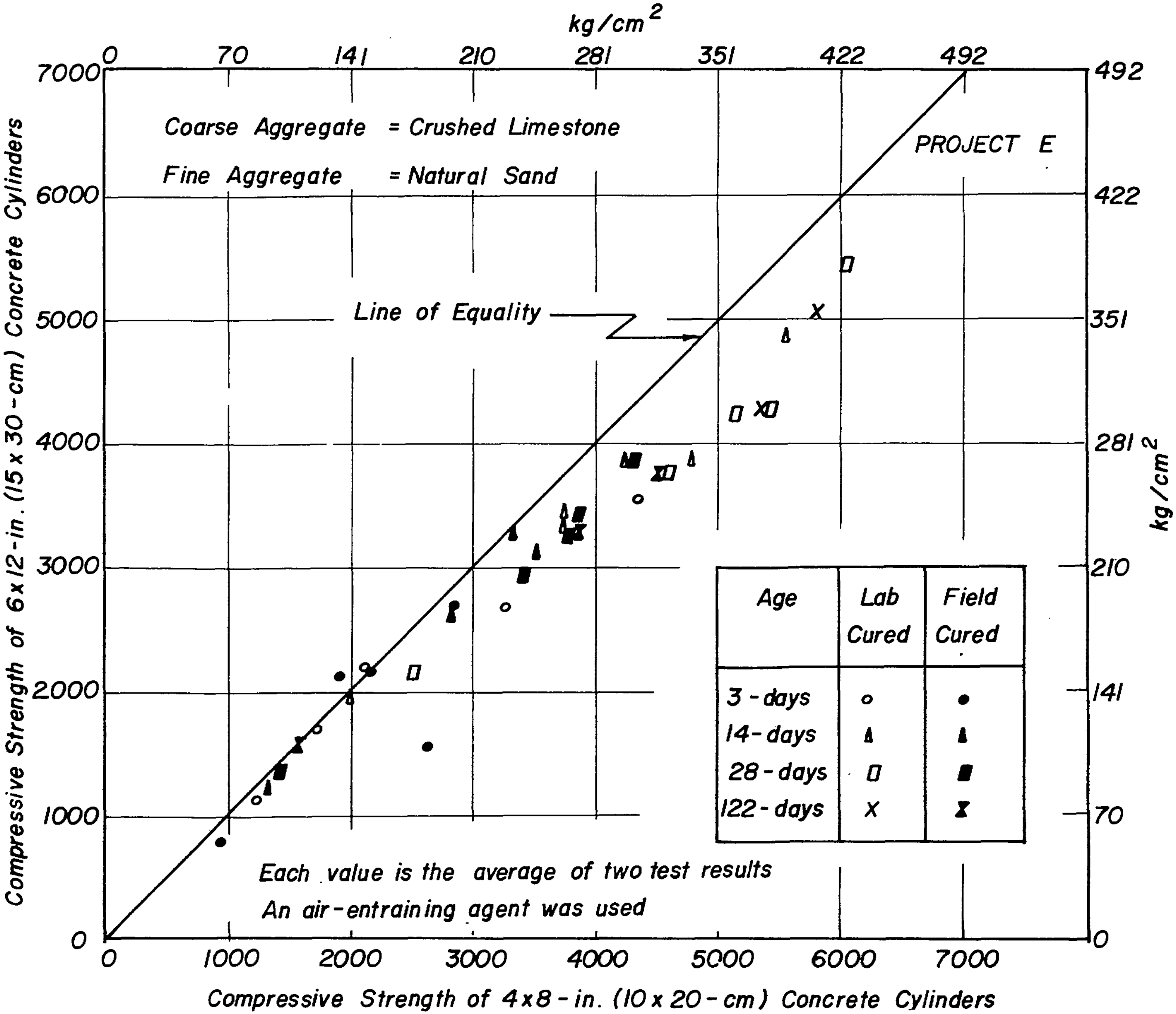

Fig. 8 - Relationship between strength of 4 x 8-in. (10 x 20-cm) and 6 x 12-in. (15 x 30-cm) cylinders - Project E.

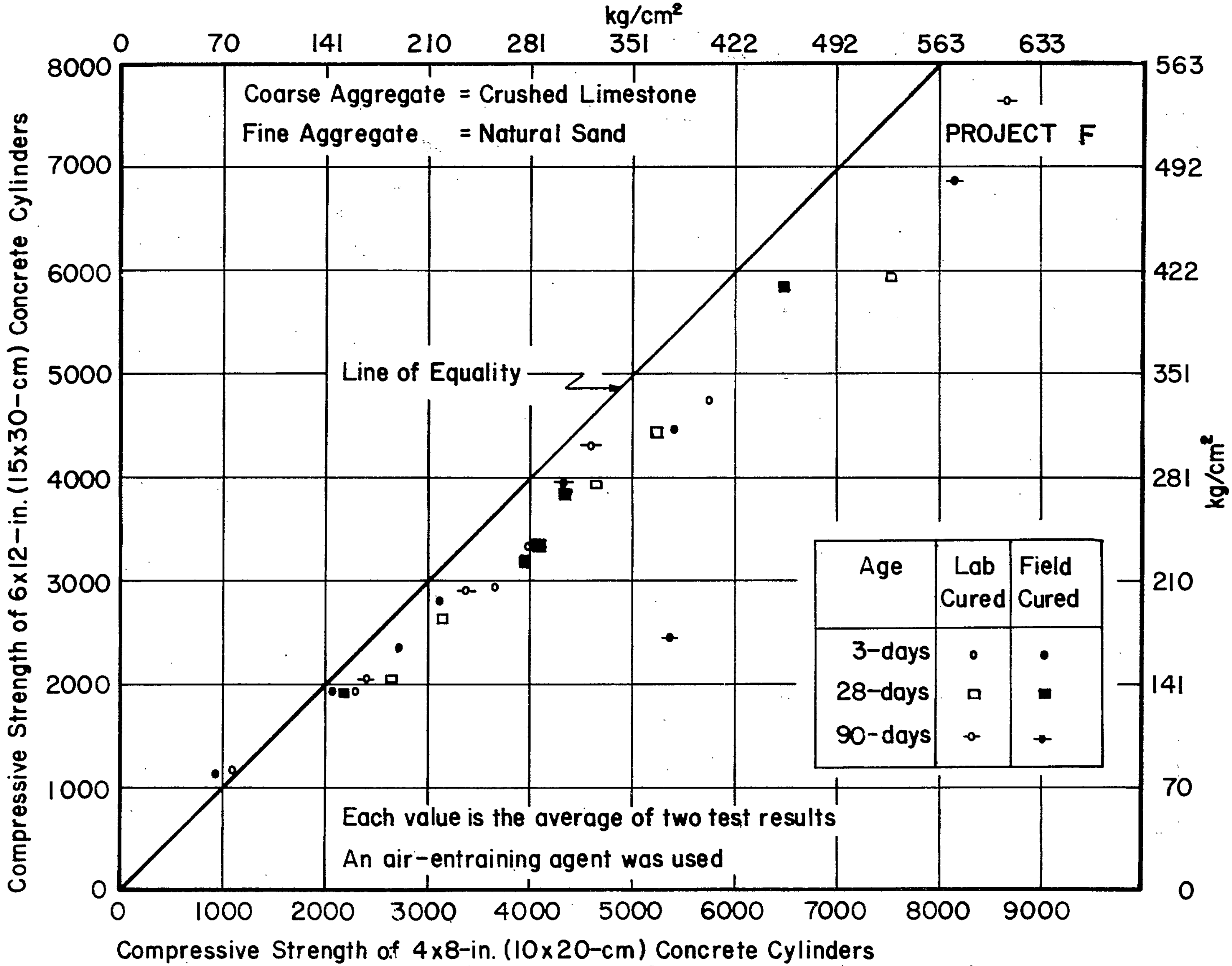

Figure 9. Relationship between strength of 4 x 8-inch (10 x 20-cm) and 6 x 12-inch (15 x 30-cm) cylinders - Project F.

TABLE 1

Physical Properties and Chemical Analyses of the Cement* - Project "A"

Description of Test	
Physical Tests, General	
Time of Set (Vicat Needle): Initial	1 hr 15 min
Final	4 hr 50 min
Fineness: No. 200 (Passing)..............	97.9 per cent
Soundness - Autoclave.....................	0.2 per cent
Physical Tests - Mortar Strength	
Compressive Strength of 2-in. (5-cm) cubes	
3-day..............................	2340 psi (164 kg/cm^2)
7-day..............................	3850 psi (271 kg/cm^2)
28-day.............................	5370 psi (378 kg/cm^2)
Chemical Analysis	
Insoluble Residue.......................	0.12 per cent
Silicon dioxide (SiO_2)	21.1 per cent
Aluminum Oxide (Al_2O_3)	5.8 per cent
Ferric Oxide (Fe_2O_3)	2.6 per cent
Calcium Oxide (CaO) Total	64.1 per cent
Magnesium Oxide (MgO)	2.9 per cent
Sulphur Trioxide (SO_3)	2.2 per cent
Loss on Ignition	0.34 per cent
Others	0.12 per cent

*Test results and chemical analyses supplied by the cement manufacturing company.

APPENDIX TABLES

TABLE 2

Grading of Aggregates - Project "A"

Coarse Aggregate		Fine Aggregate	
Sieve size	Percentage retained	Sieve size	Percentage retained
3/4-in. (19-mm)	33.3	4-mesh 8-mesh	0 10.0
3/8-in. (9.5-mm)	66.6	16-mesh 30-mesh	32.5 57.5
No. 4	100.0	50-mesh 100-mesh Pan	80.0 94.0 100.0

TABLE 3

Physical Properties of Coarse and Fine Aggregates - Project "A"

	River Gravel	Crushed Limestone	Natural Sand
Specific Gravity	2.72	2.68	2.70
Absorption, %	0.40	0.40	0.50

TABLE 4

Mix Proportions and Properties of Fresh Concrete - Project "A"

Mix Series	Mix No.	Mix Proportions		Properties of Fresh Concrete						
		Water/Cement Ratio*	Aggregate/Cement Ratio*	Temp °F	Temp °C	Slump in.	Slump cm	Unit Weight lb/cu ft	Unit Weight kg/cu m	Air Content %
I	1	**	**	72	22	3.0	7.6	140.4	2249	5.5
	2	0.67	7.76	70	21	2.5	6.4	142.2	2278	5.1
	3	0.57	6.52	70	21	2.5	6.4	143.4	2297	5.1
Gravel	4	0.46	5.28	73	23	3.0	7.6	144.8	2320	5.0
Concrete	5	0.44	4.70	70	21	3.0	7.6	145.2	2326	4.3
	6	0.41	4.45	72	22	3.0	7.6	148.0	2371	3.9
	7	0.39	3.95	72	22	3.5	8.9	146.8	2352	4.0
	8	0.33	3.04	70	21	2.5	6.4	148.8	2384	3.1
II	1	0.71	8.43	73	23	3.0	7.6	135.2	2166	5.5
	2	0.69	7.76	73	23	3.0	7.6	142.8	2287	4.2
Limestone	3	0.57	6.51	70	21	3.0	7.6	142.4	2281	5.0
	4	0.46	5.28	74	23	3.0	7.6	145.6	2332	4.0
Concrete	5	0.41	4.45	74	23	2.75	7.0	143.2	2294	5.0
	6	0.39	3.94	74	23	2.75	7.0	147.0	2355	4.0
	7	0.34	3.05	74	23	2.25	5.7	147.0	2355	4.1

* All ratios are by weight.
** Not available.

TABLE 5

Densities of Standard Cured Cylinders at 28-Days - Project "A"

Type of Concrete	Mix No.	Density			
		6 x 12-in. (15 x 30-cm)		4 x 8-in. (10 x 20-cm	
		lb /ft^3	kg/m^3	lb /ft^3	kg/m^3
Gravel Concrete	1	141.62	2269	141.57	2268
	2	143.79	2303	143.85	2304
	3	145.39	2329	144.67	2317
	4	146.60	2348	146.77	2351
	5	147.42	2361	147.84	2368
	6	148.70	2382	150.60	2412
	7	148.66	2381	149.21	2390
	8	150.32	2408	150.39	2409
Limestone Concrete	1	142.58	2284	139.31	2232
	2	145.04	2323	144.20	2310
	3			145.36	2328
	4	147.48	2362	147.46	2362
	5	144.48	2314	143.91	2305
	6	149.26	2391	149.94	2402
	7	147.90	2369	147.78	2367

TABLE 6

Within-Batch Standard Deviation and Coefficient of Variation - Limestone Concrete - Project "A"

Mix No.	7-Day						28-Day					
	6x12-in.(15x30-cm) Cylinders			4x8-in.(10x20-cm) Cylinders			6x12-in.(15x30-cm) Cylinders			4x8-in.(10x20-cm) Cylinders		
	Average Strength psi(kg/cm²)	S.D., psi (kg/cm²)	C.V., %	Average Strength psi(kg/cm²)	S.D., psi (kg/cm²)	C.V., %	Average Strength psi(kg/cm²)	S.D., psi (kg/cm²)	C.V., %	Average Strength psi(kg/cm²)	S.D., psi (kg/cm²)	C.V., %
1	1625 (114)	46 (3.2)	2.3	-	-	-	2120 (149)	39 (2.7)	1.5	2375 (167)	21 (1.5)	0.9
2	1995 (140)	21 (1.5)	0.7	2090 (147)	85 (6.0)	4.1	2540 (179)	99 (7.0)	2.6	2820 (198)	134 (9.4)	4.8
3	2985 (210)	212 (14.9)	5.8	3070 (216)	67 (4.7)	2.2	3855 (271)	346 (24.3)	7.5	3795 (266)	219 (15.4)	5.8
4	3670 (258)	14 (1.0)	0.3	4080 (287)	311 (21.9)	7.6	4630 (325)	113 (7.9)	2.3	4850 (341)	71 (5.0)	1.5
5	3875 (272)	78 (5.5)	1.7	4205 (296)	79 (5.5)	1.9	4415 (310)	110 (7.7)	2.1	4330 (304)	354 (24.9)	8.2
6	4255 (299)	35 (2.5)	2.2	4010 (282)	293 (20.6)	7.3	4980 (350)	42 (2.9)	2.0	5390 (379)	399 (28.0)	7.4
7	4510 (317)	78 (5.5)	2.0	4460 (313)	92 (6.5)	2.1	5310 (373)	134 (9.4)	3.0	5295 (372)	375 (26.4)	7.1

TABLE 7

Within-Batch Standard Deviation and Coefficient of Variation - Gravel Concrete - Project "A"

Mix No.	7-Day						28-Day					
	6x12-in. (15x30-cm) Cylinders			4x8-in. (10x20-cm) Cylinders			6x12-in. (15x30-cm) Cylinders			4x8-in. (10x20-cm) Cylinders		
	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D. psi (kg/cm^2)	C.V., %
1	1185 (83)	60 (4.2)	2.8	990 (70)	88 (6.2)	8.9	1510 (106)	35 (2.5)	1.1	1345 (95)	35 (2.5)	2.6
2	2135 (150)	106 (7.4)	4.0	2240 (157)	39 2.7)	1.7	3130 (220)	163 (11.5)	4.5	3495 (246)	212 (14.9)	6.1
3	2625 (184)	88 (6.2)	2.7	2980 (209)	28 (2.0)	1.0	3635 (255)	106 (7.4)	2.5	4090 (287)	156 (11.0)	3.8
4	3280 (231)	53 (3.7)	1.5	3415 (240)	269 (18.9)	7.9	4195 (295)	166 (11.7)	3.7	4550 (320)	71 (5.0)	1.6
5	3510 (247)	67 (4.7)	1.3	3860 (271)	88 (6.2)	2.3	4370 (307)	46 (3.2)	0.8	4590 (323)	11 (0.8)	2.3
6	3595 (253)	57 (4.0)	4.8	4185 (294)	67 (4.7)	1.6	4450 (313)	42 (2.9)	2.8	5025 (353)	779 (54.8)	15.5
7	4390 (309)	95 (6.7)	2.2	4580 (322)	282 (19.8)	6.2	4740 (333)	262 (18.4)	5.5	-	79 (5.5)	1.3
8	5050 (255)	174 (12.2)	5.0	5255 (369)	134 (9.4)	2.6	6115 (430)	46 (13.2	1.1	5970 (420)	297 (20.9)	5.0

TABLE 8

Grading of Aggregates - Project "B"

Coarse Aggregate		Fine Aggregate	
Sieve size	Percentage retained	Sieve size	Percentage retained
3/4-in. (19-mm)	33.3	4-mesh 8-mesh	0 10.0
3/8-in. (9.5-mm)	66.6	16-mesh 30-mesh	32.5 57.5
No. 4	100.0	50-mesh 100-mesh Pan	80.0 94.0 100.0

TABLE 9

Physical Properties of Coarse and Fine Aggregates-Project "B"

	Crushed Limestone	Natural Sand
Specific Gravity	2.68	2.70
Absorption %	0.40	0.50

TABLE 10

Mix Proportions and Properties of Fresh Concrete-Project"B"

Mix Proportions			Properties of Fresh Concrete						
Mix No.	Water/Cement Ratio*	Aggregate/Cement Ratio*	Temp		Slump		Unit Weight		Air Content, %
			°F	°C	in.	cm	lb/ft^3	kg/m^3	
1	0.65	7.77	73	22.8	2.5	6.4	142.0	2275	5.1
2	0.46	5.28	74	23.3	3.0	7.6	143.6	2300	5.6
3	0.68	7.76	76	24.4	2.75	7.0	137.4	2201	6.2
4	0.56	6.40	77	25.0	2.75	7.0	141.2	2262	5.4
5	0.34	3.04	77	25.0	2.0	5.1	146.2	2342	3.7

* All ratios are by weight.

Note: Concrete made in two batches of 2 cu ft each and the above values are the average of the two batches.

TABLE 11

Within-Batch Standard Deviation and Coefficient of Variation for 7- and 28-Day Results-Project "B"

Mix No.	7-Day						28-Day					
	6x12-in. (15x30-cm) cylinders			4x8-in. (10x20-cm) cylinders			6x12-in. (15x30-cm) cylinders			4x8-in. (10x20-cm) cylinders		
	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	2020 (142)	15 (1.0)	0.8	2315 (163)	181 (12.7)	7.8	2815 (198)	10 (0.7)	0.4	3330 (234)	435 (30.6)	13.0
2	3140 (220)	302 (21.2)	9.6	3950 (278)	88 (6.2)	2.2	4585 (322)	95 (6.7)	2.1	5340 (375)	112 (7.9)	2.1
3	2090 (147)	92 (6.4)	4.4	2210 (155)	63 (4.4)	2.8	2790 (196)	43 (3.0)	1.5	2910 (205)	48 (3.4)	1.6
4	3115 (219)	57 (4.0)	1.8	3365 (237)	20 (1.4)	0.6	4065 (286)	43 (3.0)	1.1	4145 (291)	184 (12.9)	4.4
5	4585 (322)	130 (9.1)	2.8	5050 (355)	114 (8.0)	2.3	5250 (369)	100 (7.0)	1.9	6515 (458)	78 (5.5)	1.2

TABLE 12

Within-Batch Standard Deviation and Coefficient of Variation for 42-and 91-Day Results-Project "B"

Mix No.	42-Day						91-Day					
	6x12-in. (15x30-cm) cylinders			4x8-in. (10x20-cm) cylinders			6x12-in. (15x30-cm) cylinders			4x8-in. (10x20-cm) cylinders		
	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	3235 (227)	49 (3.4)	1.5	3620 (254)	218 (15.3)	6.0	3285 (231)	176 (12.4)	5.4	4110 (289)	149 (10.5)	3.6
2	4965 (349)	166 (11.7)	3.3	5290 (372)	(216) (15.2)	4.1	5415 (381)	117 (8.2)	2.1	5910 (415)	335 (23.6)	5.7
3	2960 (208)	21 (1.5)	0.7	2970 (209)	80 (5.6)	2.7	3215 (226)	48 (3.4)	1.5	3595 (253)	62 (4.4)	1.7
4	4220 (297)	84 (5.9)	2.0	4485 (315)	31 (2.2)	0.7	4440 (312)	68 (4.8)	1.5	4970 (349)	28 (1.9)	0.6
5	5875 (413)	22 (1.5)	0.4	6620 (465)	358 (25.2)	5.4	6595 (464)	103 (7.2)	1.6	7615 (535)	86 (6.0)	1.1

TABLE 13

Grading of Aggregates-Project "C"

Coarse Aggregate		Fine Aggregate	
Sieve Size	Percentage retained	Sieve Size	Percentage retained
3/4-in.(19-mm)	2.2	4-mesh	5.2
3/8-in.(9.5-mm)	76.3	8-mesh	12.9
		16-mesh	28.2
		30-mesh	57.8
No. 4	98.1	50-mesh	80.0
		100-mesh	94.0
		Pan	100.0

TABLE 14

Physical Properties of Coarse and Fine Aggregates - Project "C"

	Crushed Limestone	Natural Sand
Specific Gravity	2.80	2.67
Absorption, %	0.40	0.50

TABLE 15

Densities of Standard Cured Cylinders at Various Ages - Project "C"

Age	Density* of Test Cylinders			
	6 x 12-in. (15 x 30-cm)		4 x 8-in. (10 x 20-cm)	
	lb/ft^3	kg/m^3	lb/ft^3	kg/m^3
2 months	146.88	2353	146.93	2353
3 months	146.72	2350	147.00	2355
4 months	146.60	2348	147.60	2350

* Each value is the average of two test results

TABLE 16

Mix Proportions and Properties of Fresh Concrete - Project "C"

Mix Proportions		Properties of Fresh Concrete						
Water/Cement Ratio	Aggregate/Cement Ratio	Temp		Slump		Unit Weight		Air Content %
		oF	oC	in.	cm	lb/ft	kg/m^3	
0.63	1. 8.20	60	15.6	3	7.6	144.4	2313	5.6

TABLE 17

Within-Batch Standard Deviation and Coefficient of Variation for Test Results at Various Ages - Project "C"

Age	6 x 12-in. (15 x 30-cm) cylinders			4 x 8-in. (10 x 20-cm) cylinders		
	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
3-Day	2615 (184)	18 (1.3)	0.7	2925 (206)	85 (5.9)	2.9
14-Day	3415 (240)	177 (12.4)	5.2	4220 (297)	42 (2.9)	1.0
28-Day	3700 (260)	67 (4.7)	1.8	4655 (327)	107 (7.5)	2.3
2 Months	3915 (275)	42 (2.9)	1.1	5195 (365)	50 (3.5)	1.0
3 Months	4330 (304)	99 (6.9)	2.3	5060 (356)	57 (4.0)	1.1
4 Months	4605 (324)	15 (1.0)	0.3	5120 (360)	84 (5.9)	1.6

TABLE 18

Mix Proportions and Properties of Fresh Concrete - Project "D"

Mix No.	Mix Design Data*				Properties of Fresh Concrete						
	Nominal Water/Cement Ratio by Weight	Cement Content		Aggregate/Cement Ratio by Weight	Temperature		Slump,		Unit Weight,		Air Content, Per Cent
		lb/yd^3	kg/m^3		° F	° C	in.	cm	lb/ft^3	kg/m^3	
1	0.67	410	243	8.25	64	18	2.0	5.1	148.4	2377	3.8
2	0.77	360	214	9.46	50	10	2.5	6.4	141.6	2268	3.6
3	0.56	500	297	6.76	62	17	**	**	133.2	2134	9.5
4	0.46	630	374	5.06	52	11	5.0	12.7	140.4	2249	7.0
5	0.42	700	415	4.39	64	18	3.5	8.9	145.6	2333	5.0

* Supplied by the ready-mixed company which delivered the concrete.
** Slump exceeded 6 in. (15 cm).

Note: All concrete supplied by a local ready mix concrete producer.
For gradings and physical properties of coarse and fine aggregates see Table 13 - Project C.

TABLE 19

Densities of Standard-Cured Test Cylinders at Different Ages - Project "D"

Mix No.	28-Day				91-Day			
	6 x 12-in. (15 x 30-cm)		4 x 8-in. (10 x 20-cm)		6 x 12-in. (15 x 30-cm)		4 x 8-in. (10 x 20-cm)	
	lb/cu^3	kg/m^3	lb/cu^3	kg/m^3	lb/cu ft	kg/m^3	lb/ft^3	kg/m^3
1	150.89	2417	150.94	2418	148.01	2371	147.78	2367
2	136.89	2193	137.33	2200	137.92	2207	138.37	2217
3	150.56	2412	150.81	2416	149.18	2390	151.03	2420
4	141.33	2264	141.54	2268	141.87	2273	141.29	2264
5	146.16	2341	147.01	2355	146.87	2353	147.47	2363

TABLE 20

Compressive Strength of Standard- and Field-Cured Test Cylinders of Different Sizes - Project "D"

Mix No.	Curing Condition	7-day		14-day		28-day		91-day		218-day	
		6x12-in. (15x30-cm)	4x8-in. (10x20-cm)	6x12-in. (15x30-cm)	4x8-in. (10x20-cm)	6x12-in. (15x30-cm)	4x8-in. (10x20-cm)	6x12-in. (15x30-cm)	4x8-in. (10x20-cm)	6x12-in. (15x30-cm)	4x8-in. (10x20-cm)
1	Standard	3920 (276)	3405** (239)	-	-	4660 (328)	4025 (283)	5300 (373)	5370 (378)	5550 (390)	6220** (437)
	Field	1570 (110)	1105 (78)	-	-	2000 (141)	+	+	3425** (241)	+	+
2	Standard	1905 (134)	1680 (118)	-	-	2265 (159)	1895 (133)	2550 (179)	2440 (172)	2545 (179)	+
	Field	475 (34)	710 (50)	-	-	1140 (80)	1460 (103)	1010 (71)	1640 (115)	+	+
3	Standard	-	-	3655 (257)	3735 (263)	4110 (289)	4430 (311)	4320 (304)	5310 (373)	4880 (343)	5580 (392)
	Field		-	1225 (86)	1395 (98)	1565 (110)	1770 (124)	2780 (195)	3495 (246)	+	+
4	Standard	-	-	3995 (281)	4520 (318)	4100 (288)	5045 (355)	5130 (361)	+	5200 (366)	6055 (426)
	Field	-	-	2740 (193)	3015 (212)	2355 (166)	2990 (210)	4150 (292)	4780 (336)	+	+
5	Standard	-	-	4965 (349)	5540* (389)	5565 (391)	6215 (437)	6350 (446)	+	7000 (492)	6710 (472)
	Field	-	-	3855 (271)	4095** (288)	3330 (234)	3420 (240)	5200 (366)	6180 (435)	+	+

* For Mix Series 4 and 5, age at testing was 217 days.
** Only one cylinder available for testing.
\+ Test results not available.

TABLE 21

Within-Batch Standard Deviation and Coefficient of Variation of 28-Day Test Results - Project "D"

Mix No.	Standard-Cured Cylinders						Field-Cured Cylinders					
	6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)			6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)		
	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V. %	Average Strength psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V. %	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	4660 (328)	67.1 (4.7)	1.4	4025 (283)	672 (47.2)	16.7	2000 (141)	226 (15.9)	11.3	1415 (100)	421 (29.6)	29.7
2	2265 (159)	247 (17.3)	10.9	1895 (133)	21 (1.5)	1.1	1140 (80)	113 (7.9)	9.9	1460 (103)	240 (16.9)	16.5
3	4110 (289)	138 (9.7)	3.3	4430 (311)	195 (13.7)	4.4	1565 (110)	64 (4.5)	4.1	1770 (124)	28 (2.0)	1.6
4	4100 (288)	184 (12.9)	4.5	5045 (355)	573 (40.3)	11.4	2355 (166)	78 (5.5)	3.3	2990 (210)	71 (5.0)	2.4
5	5565 (391)	113 (7.9)	2.0	6215 (437)	233 (16.4)	3.8	3330 (234)	7 (0.49)	0.2	3420 (240)	113 (7.9)	3.3

TABLE 22

Within-Batch Standard Deviation and Coefficient of Variation of 91-Day Test Results - Project "D"

Mix No.	Standard-Cured Cylinders						Field-Cured Cylinders					
	6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)			6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)		
	Average+ Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average+ Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average+ Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average+ Strength psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	5300 (373)	99 (6.9)	1.9	5370 (378)	212 (14.9)	4.0	+	+	+	3425* (241)	-	-
2	2550 (179)	42 (2.9)	1.7	2440 (172)	127 (8.9)	5.2	1010 (71)	88 (6.2)	8.7	1640 (115)	14 (1.0)	0.9
3	4320 (305)	110 (7.7)	2.5	5310 (373)	57 (4.0)	1.1	2780 (195)	49 (3.4)	1.8	3495 (246)	7 (0.5)	0.2
4	-	-	-	-	-	-	4150 (292)	113 (7.9)	2.7	4780 (336)	50 (3.5)	1.0
5	-	-	-	-	-	-	5200 (366)	307 (21.6)	5.9	6180 (435)	159 (11.2)	2.6

+Each value is the average of tests on two specimens unless otherwise stated.
*Only one cylinder tested.

Table 23

Mix Proportions and Properties of Fresh Concrete - Project "E"

Mix No.	Mix Proportions*				Properties of Fresh Concrete						
	Nominal Water/Cement Ratio by Weight	Cement Content		Aggregate/Cement Ratio by Weight	Temperature		Slump,		Unit Weight,		Air Content, Per Cent
		lb/yd^3	kg/m^3		°F	°C	in.	cm	lb/ft^3	kg/m^3	
1	0.77	360	214	9.46	60	16	**2.0	5.2	144.8	2319	4.4
2	0.67	410	243	8.25	74	23	2.75	7.0	148.0	2370	4.0
3	0.56	500	297	6.76	72	22	2.5	6.4	148.8	2383	3.5
4	0.46	630	374	5.06	68	20	3.5	8.9	145.2	3226	5.0
5	0.42	700	415	4.39	68	20	3.5	8.9	***	***	***

* Concrete supplied by the ready-mixed company which delivered the concrete.
** Slump taken 45 minutes after the truck arrived at site.
*** Air content and unit weight not determined due to faulty operation of the air meter.

Note: All concrete supplied by a local ready mix concrete producer.
For gradings and physical properties of coarse and fine aggregates see Table 13 - Project C.

TABLE 24

Within-Batch Standard Deviation and Coefficient of Variation of 3-Day Test Results - Project "E"

Mix No.	Standard-Cured Cylinders						Field-Cured Cylinders					
	6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)			6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)		
	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi (kg/cm^2)	S.D. psi (kg/cm^2)	C.V., %
1	1115 (78.3)	11 (0.7)	0.9	1210 (85.0)	71 (4.9)	5.8	780 (54.8)	28.3 (1.9)	3.6	980 (68.8)	0	0
2	1700 (119.5)	71 (4.9)	4.2	1715 (120.5)	25 (1.7)	1.4	2185 (153.6)	113 (7.9)	5.2	2185 (153.6)	28.3 (1.9)	1.3
3	2190 (153.9)	78 (5.4)	3.5	2115 (148.6)	31.8 (2.2)	1.5	2105 (147.9)	99 (6.9)	4.7	1960 (137.7)	229 (16.0)	11.7
4	2680 (188.4)	28 (1.9)	1.1	3270 (229.8)	28 (1.9)	0.9	1550 (108.9)	18 (1.2)	1.1	2605 (183.1)	113 (7.9)	4.3
5	3530 (248.1)	0	0	4370 (307.2)	11 (0.7)	0.2	2680 (188.4)	56 (3.9	2.1	2855 (200.7)	467 (32.8)	16.3

TABLE 25

Within-Batch Standard Deviation and Coefficient of Variation of 14-Day Test Results - Project "E"

Mix No.	Standard-Cured Cylinders						Field-Cured Cylinders					
	6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)			6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)		
	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi(kg/cm^2)	S.D. psi (kg/cm^2)	C.V., %	Average Strength psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	1980 (139.1)	14 (0.98)	0.7	2010 (141.3)	49 (3.4)	2.5	1245 (87.5)	28 (1.9)	2.3	1325 (93.1)	17.7 (1.2)	1.3
2	3450 (242.5)	42 (2.9)	1.2	3795 (266.7)	74 (5.2)	1.9	2690 (189.1)	11 (0.7)	0.4	2830 (198.9)	89 (6.2)	3.0
3	3855 (271)	35 (2.4)	0.9	4250 (298.7)	46 (3.2)	1.1	3270 (229.8)	53 (3.7)	1.6	3370 (236.9)	10.6 (0.7)	0.3
4	3890 (273.4)	56.6 (3.9)	1.4	4800 (337.4)	188 (13.2)	4.1	3110 (218.6)	67 (4.7)	2.2	3540 (248.8)	95 (6.6)	2.7
5	4885 (343.4)	21 (1.4)	0.4	5580 (292.2)	21.2 (1.4)	0.4	3325 (233.7)	78 (5.4)	2.3	3740 (262.9)	57 (4.0)	1.5

TABLE 26

Within-Batch Standard Deviation and Coefficient of Variation of 28-Day Test Results - Project "E"

Mix No.	Standard-Cured Cylinders						Field-Cured Cylinders					
	6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)			6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)		
	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	2130 (149.7)	14 (0.99)	0.7	2520 (177.1)	28 (1.9)	1.1	1365 (95.5)	7.0 (0.4)	0.5	1545 (108.6)	17.7 (1.2)	1.1
2	3760 (264.3)	67 (4.7)	1.8	4600 (323.3)	3 (0.2)	0.1	2930 (205.9)	115 (8.0)	3.9	3445 (242.1)	81 (5.6)	2.3
3	4205 (295.6)	131 (9.2)	3.1	5180 (364.1)	53 (3.7)	1.0	3335 (234.4)	88 (6.1)	2.6	3750 (263.6)	173 (12.1)	4.6
4	4290 (301.5)	184 (12.9)	4.3	5405 (379.9)	21 (1.4)	0.4	3440 (241.8)	60 (4.2)	1.7	3900 (274.1)	67 (4.7)	1.7
5	5450 (383.1)	25 (1.7)	0.4	6090 (428.1)	286 (20.1)	4.7	3860 (271.3)	117 (8.2)	3.0	4300 (302.2)	170 (11.9)	3.9

TABLE 27

Within-Batch Standard Deviation and Coefficient of Variation of 122-Day Test Results - Project "E"

Mix No.	Standard-Cured Cylinders						Field-Cured Cylinders					
	6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)			6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)		
	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	2635 (185.2)	74 (5.2)	2.8	2685 (188.7)	141 (9.9)	5.3	1545 (108.6)	64 (4.4)	4.1	1590 (111.7)	56 (3.9)	3.6
2	4255 (299.1)	35 (2.4)	8.3	5395 (379.2)	85 (5.9)	1.6	3300 (231.9)	95 (6.6)	2.9	3880 (272.7)	127 (8.9)	3.3
3	5030 (353.6)	88 (6.1)	1.8	5800 (407.7)	102 (7.1)	1.8	3760 (264.3)	35 (2.4)	9.4	4510 (317.0)	7.1 (0.4)	0.2
4	6120 (430.2)	633 (44.4)	10.3	6530 (459.0)	315 (22.1)	4.8	2920 (205.2)	242 (17.0)	8.3	4460 (313.5)	59 (4.1)	1.3
5	-	-	-	-	-	-	-	-	-	-	-	-

TABLE 28

Mix Proportions and Properties of Fresh Concrete - Project "F"

Mix No.	Mix Proportions		Properties of Fresh Concrete						
	Water/Cement Ratio*	Aggregate/Cement Ratio*	Temp		Slump		Unit Weight		Air Content %
			°F	°C	in.	cm	lb/m^3	kg/m^3	
1	0.43	1. 5.05	70	21.1	2.5**	6.4	148.0	2371	3.6**
2	0.52	1. 6.50	76	24.4	5	12.7	144.8	2319	4.2
3	0.63	1. 8.20	73	22.8	3	7.6	143.6	2300	5.5
4	0.71	1. 9.40	72	22.2	2.5	6.4	144.8	2319	5.2
5	0.79	1.10.80	67	19.4	2.25	5.7	144.4	2313	2.7

* All ratios are by weight

** Slump and air taken one-half hour after the arrival of mixer at site

Note: All concrete supplied by a local ready mix concrete producer.
For gradings and physical properties of coarse and fine aggregates see Table 13 - Project C.

TABLE 29

Within-Batch Standard Deviation and Coefficient of Variation of 3-Day Results - Project "F"

Mix No.	Standard-Cured Cylinders						Field-Cured Cylinders					
	6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)			6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)		
	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	4795 (337)	64 (4.5)	1.3	5755 (404)	148 (10.4)	2.6	4480 (315)	265 (18.6)	5.9	5430 (382)	78 (5.5)	1.4
2	3325 (234)	38 (2.7)	1.1	4000 (281)	28 (2.0)	0.7	2805 (197)	93 (6.5)	3.3	3100 (218)	197 (13.8)	6.4
3	2975 (209)	49 (3.4)	1.7	3660 (257)	124 (8.7)	3.4	2350 (165)	32 (2.2)	1.4	2705 (190)	177 (12.4)	6.5
4	1945 (137)	21 (1.5)	1.1	2300 (162)	95 (6.7)	4.1	1920 (135)	39 (2.7)	2.0	2035 (143)	120 (8.4)	5.9
5	1145 (80)	28 (2.0)	2.4	1105 (78)	21 (1.5)	1.9	1125 (79)	14 (0.9)	1.3	925 (65)	85 (6.0)	9.2

TABLE 30

Within-Batch Standard Deviation and Coefficient of Variation of 28-Day Results - Project "F"

Mix No.	Standard-Cured Cylinders: 6 x 12-in (15 x 30-cm) Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Standard-Cured Cylinders: 4 x 8-in. (10 x 20-cm) Average Strength, psi (kg/cm^2)	S.D. psi (kg/cm^2)	C.V., %	Field-Cured Cylinders: 6 x 12-in. (15 x 30-cm) Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Field-Cured Cylinders: 4 x 8-in. (10 x 20-cm) Average Strength, psi (kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	5990 (421)	685 (48.2)	11.4	7575 (532)	636 (44.7)	8.4	5880 (413)	10 (0.7)	0.2	6490 (456)	169 (11.9)	2.6
2	4470 (314)	12.6 (0.8)	0.3	5260 (369)	366 (25.7)	6.9	3860 (271)	205 (14.4)	5.3	4335 (305)	175 (12.3)	4.0
3	3945 (277)	122 (8.6)	3.1	4625 (325)	23 (1.6)	0.5	3335 (234)	37 (2.6)	1.1	4040 (284)	152 (10.7)	3.8
4	2680 (188)	13 (0.9)	0.5	3195 (224)	17 (1.2)	0.5	3210 (226)	62 (4.4)	1.9	3975 (279)	107 (7.5)	2.7
5	2010 (141)	5 (0.4)	0.2	2655 (187)	13 (0.9)	0.5	1920 (135)	13 (0.9)	0.7	2235 (157)	60 (4.2)	2.7

TABLE 31

Within-Batch Standard Deviation and Coefficient of Variation of 90-Day Results - Project "F"

Mix No.	Standard-Cured Cylinders						Field-Cured Cylinders					
	6 x 12-in. (15 x 30-cm)			4 x 8 -in. (10 x 20-cm)			6 x 12-in. (15 x 30-cm)			4 x 8-in. (10 x 20-cm)		
	Average Strength, psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %	Average Strength psi(kg/cm^2)	S.D., psi (kg/cm^2)	C.V., %
1	7660 (538)	448 (31.5)	5.8	8665 (609)	152 (10.7)	1.7	6865 (483)	142 (10.0)	2.1	8115 (570)	141 (9.9)	1.7
2	5195 (365)	45 (3.2)	0.9	10390 (730)	619 (43.5)	5.9	-	-	-	-	-	-
3	4355 (306)	128 (9.0)	2.9	4600 (323)	62 (4.4)	1.3	3915 (275)	108 (7.6)	2.8	4360 (307)	412 (29.0)	9.4
4	2940 (206)	32 (2.2)	1.1	3305 (232)	169 (11.9)	5.1	-	-	-	-	-	-
5	2035 (143)	102 (7.2)	5.0	2335 (164)	56 (3.9)	2.4	-	-	-	-	-	-